Recent Developments in the NIST Cryogenic Thermal Transfer Standard (CTTS) Project

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Outline

- Introduction
  - Goals
  - History
- Theory of Operation
- Design
- Transmission Line Structures
- Present Performance
- Limiting Factors
- Conclusions and Future Plans

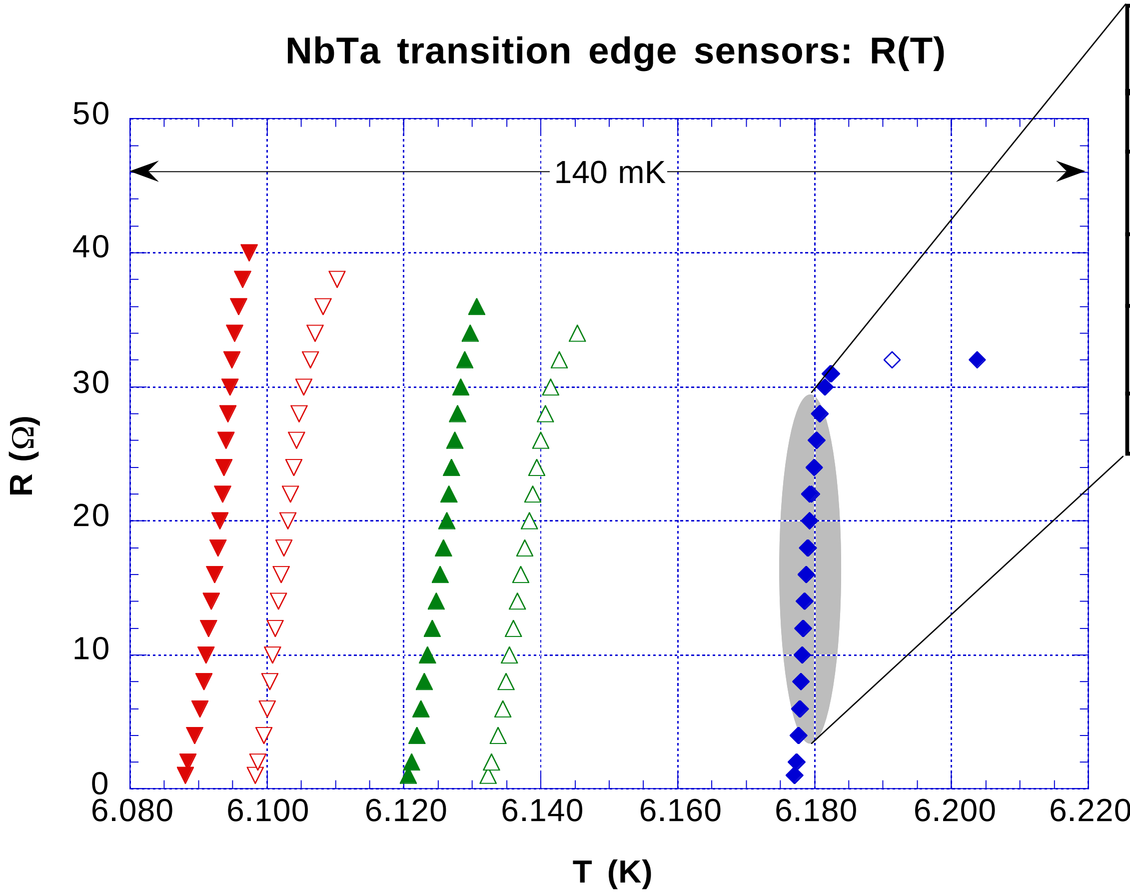
Goals

- Develop a new primary thermal transfer standard
- Low operating temperature
  - Reduce thermoelectric effects
  - Increase sensitivity
- Operate at microwatt signal power
  - Low-voltage/low-current primary standard

History

- May 1997 - first CTTS
  - 45 cm manganin input transmission line
  - Nb transition-edge sensor (TES)
  - Horizontal experimental platform
- June 1999
  - 45 cm coaxial input transmission line
  - NbTa TES
  - Vertical experimental platform
- June 2000
  - High-T_c input transmission line

TES Sensitivity

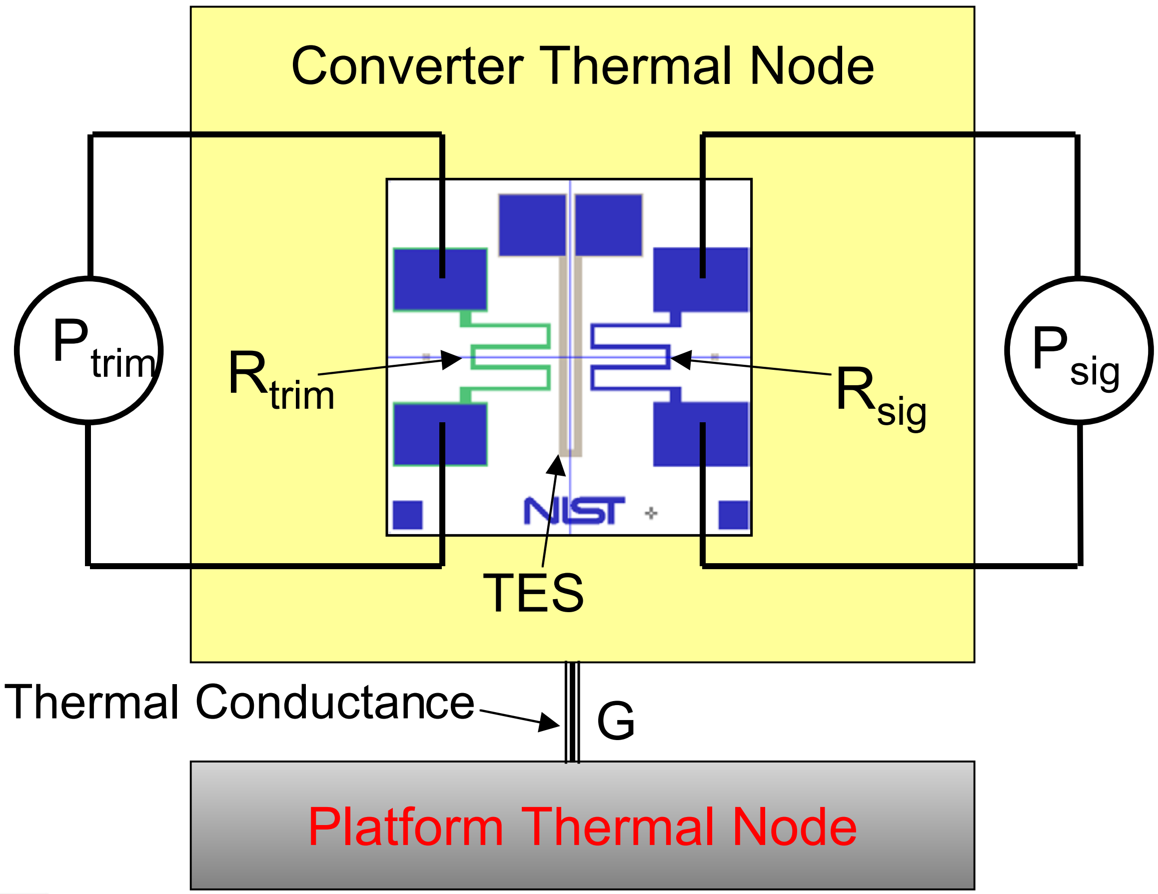


Sensor Characteristics	TES
T_c (K)	6.179
transition width (10-90%, mK)	3.1
$(dR/dT)_{peak}$ (Ω/K)	8000
$\alpha = 1/R^*(dR/dT)_{peak}$ (K^{-1})	500
$T/R^*(dR/dT)_{peak}$	3090

Sensor Characteristic	thermocouple
$T-T_{ambient}$ (C)	150-200
$(dV/dT)_{peak}$ (μV/K)	100
$1/V^*(dV/dT)_{peak}$ (K^{-1})	0.01
$T/V^*(dV/dT)_{peak}$	<1

Theory of Operation

- Electrical substitution calorimetry

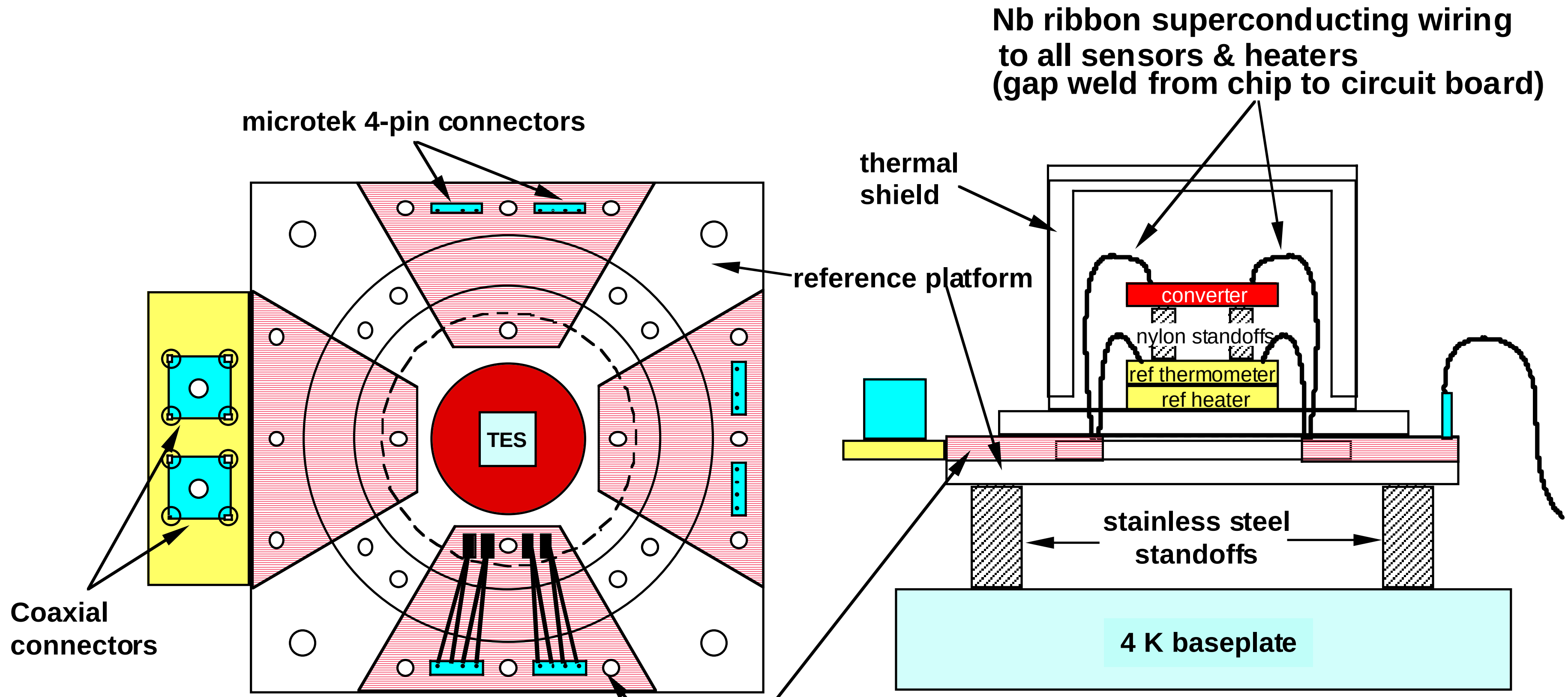


$$P_{total} = P_{trim} + P_{sig}$$

$$P_{total} = G(T_c - T_{plat})$$

$$\Delta P_{trim} = -\Delta P_{sig}$$

Experimental Platform



Circuit boards carry signals
under reference thermal shield

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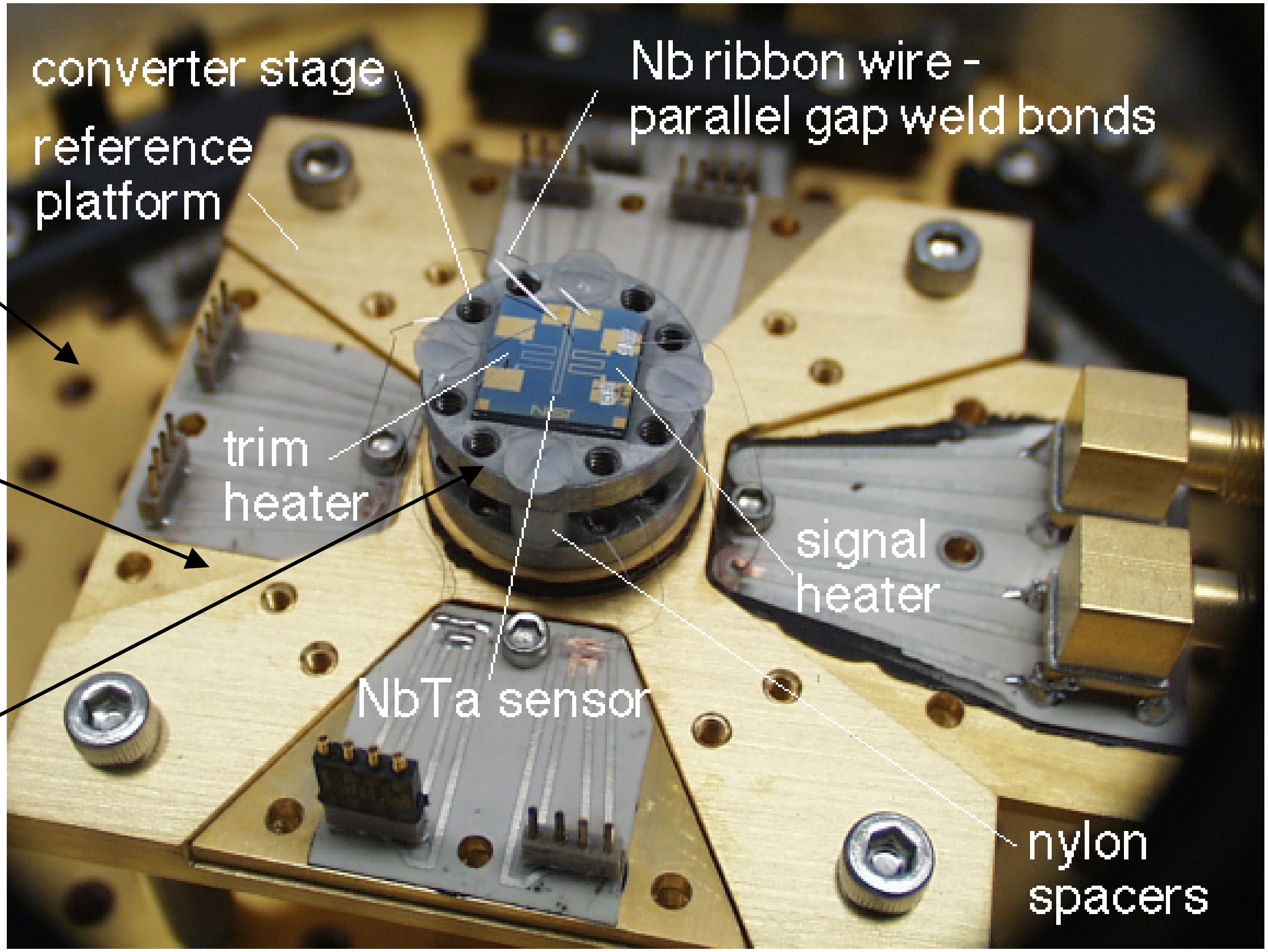
Experimental Platform

Cryostat
Baseplate
4 K

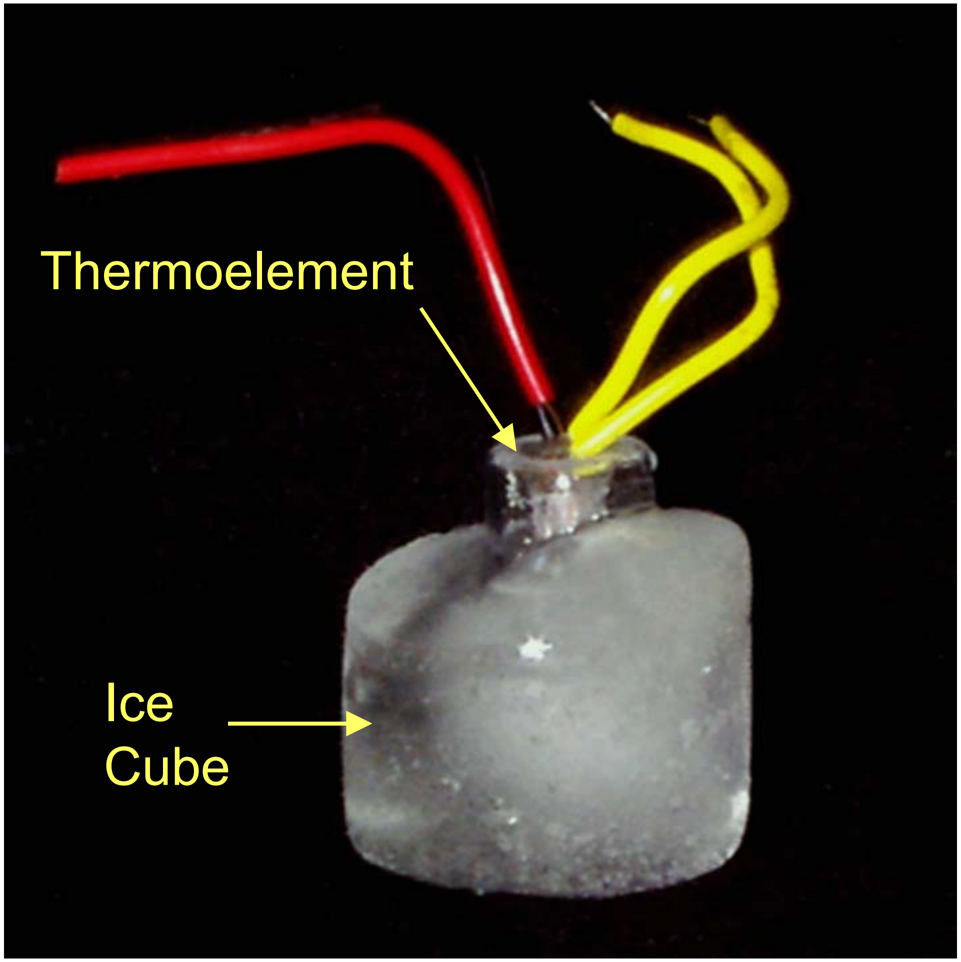
Reference
Platform
≈ 6 K

Thermal
Converter
Stage
6 K + ΔT_c



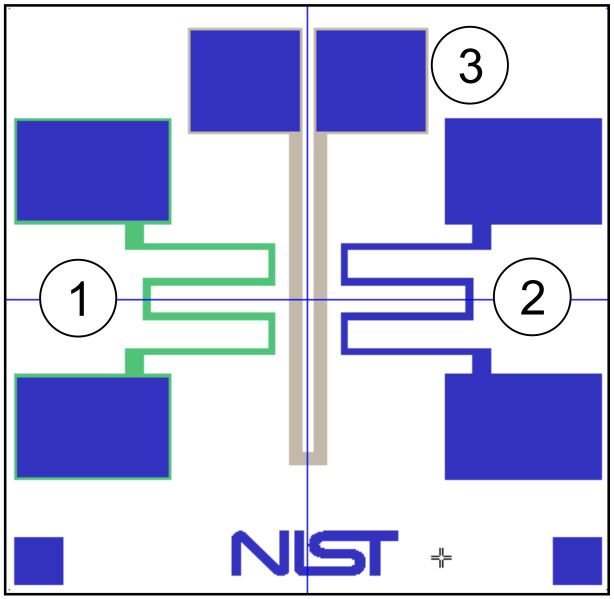
Sensor Designs - I

Original Sensor Design

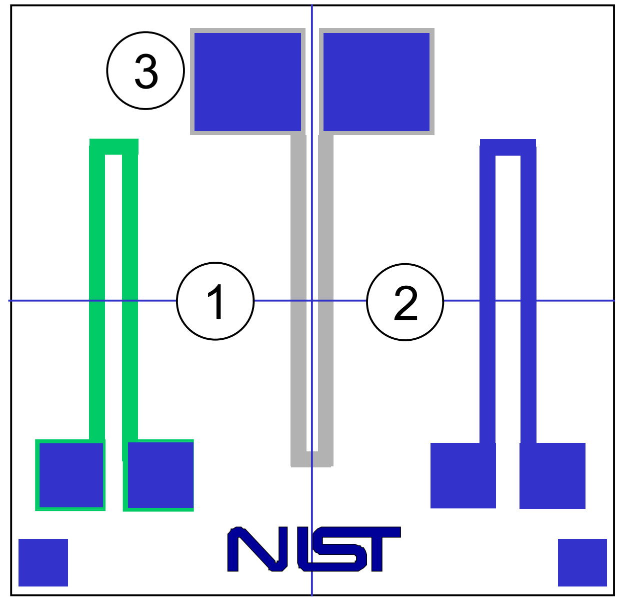


Sensor Designs - II

Old Design



New Design

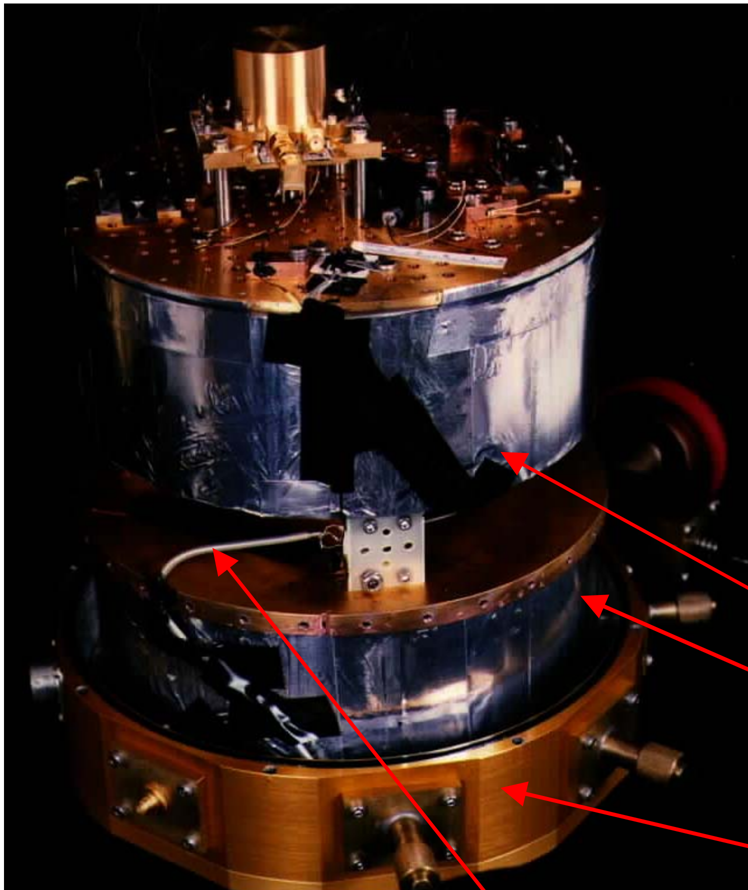


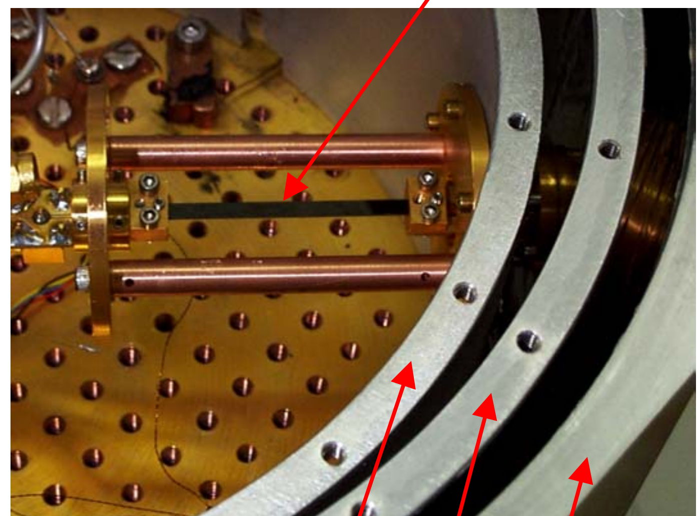
1 PdAu Trim Heater - 451 Ω

2 Au Signal Heater - 6.9 Ω

3 NbTa TES

Input Transmission Lines





High-Tc Transmission Line

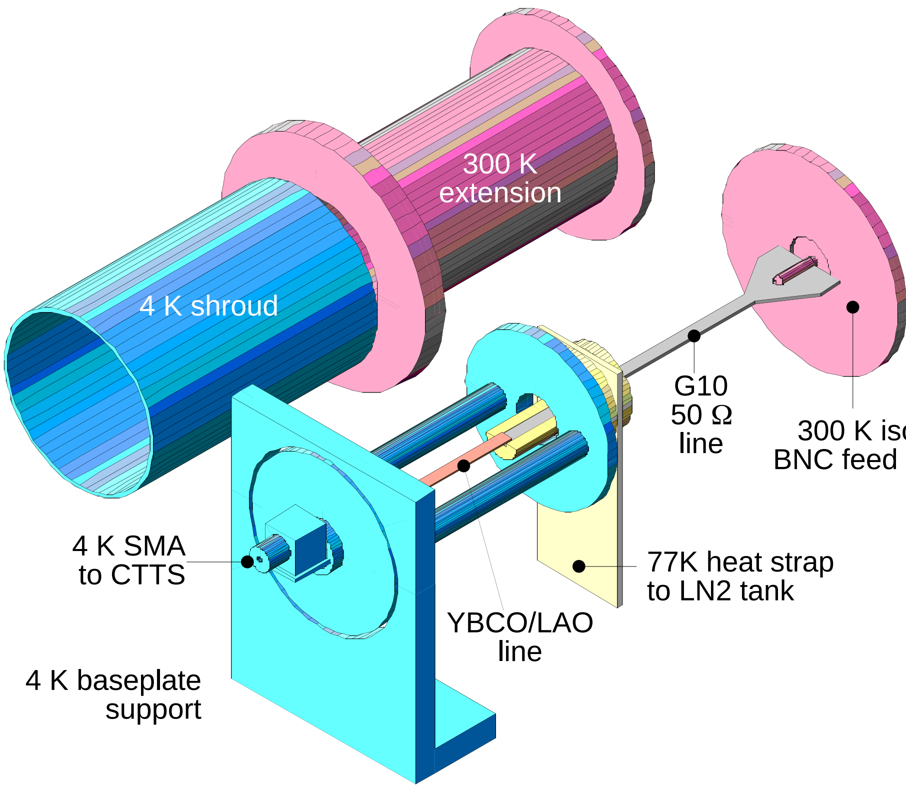
He Tank

N Tank

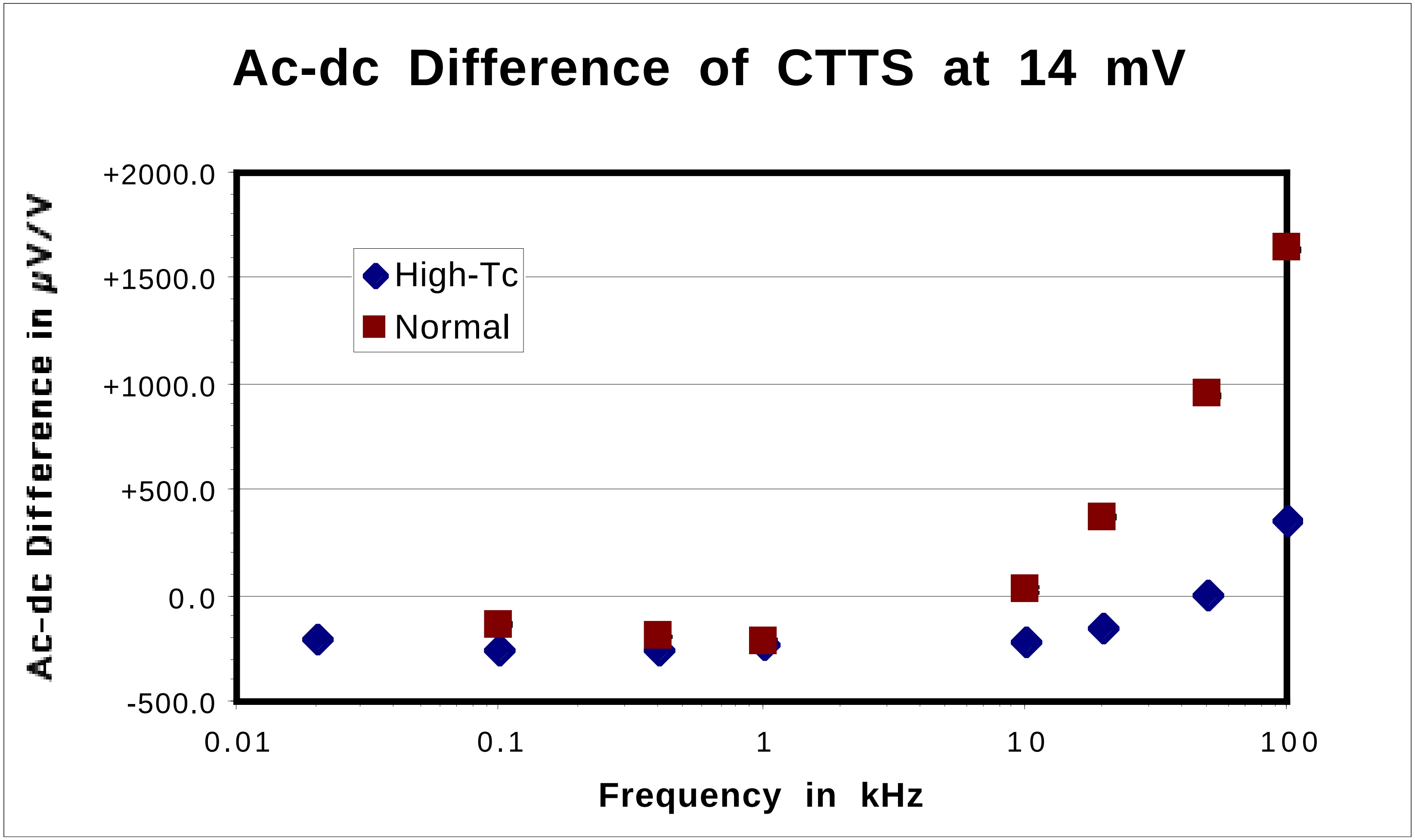
Vacuum Jacket

Normal-Metal Coaxial Transmission Line

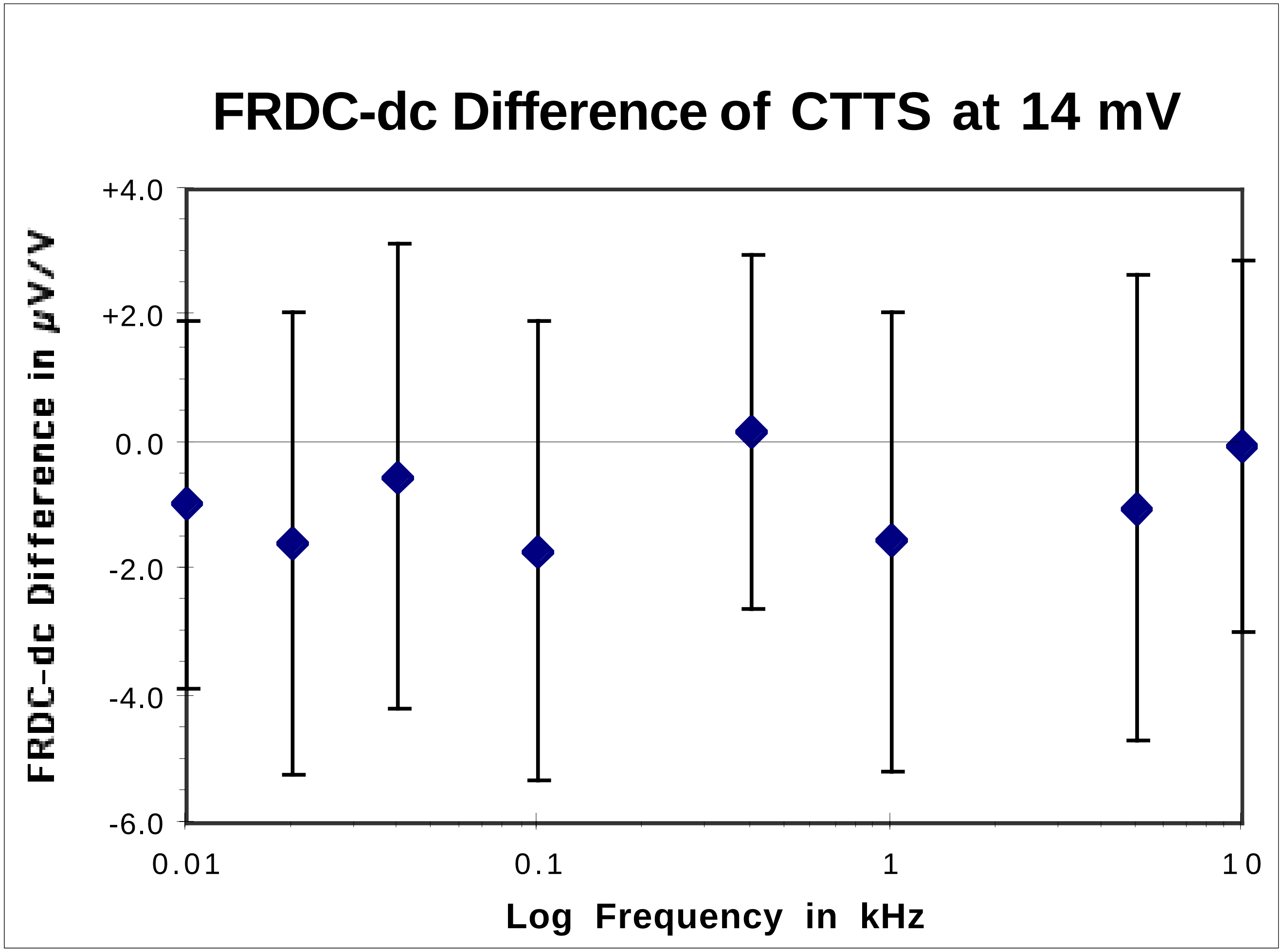
High T_c Transmission Line



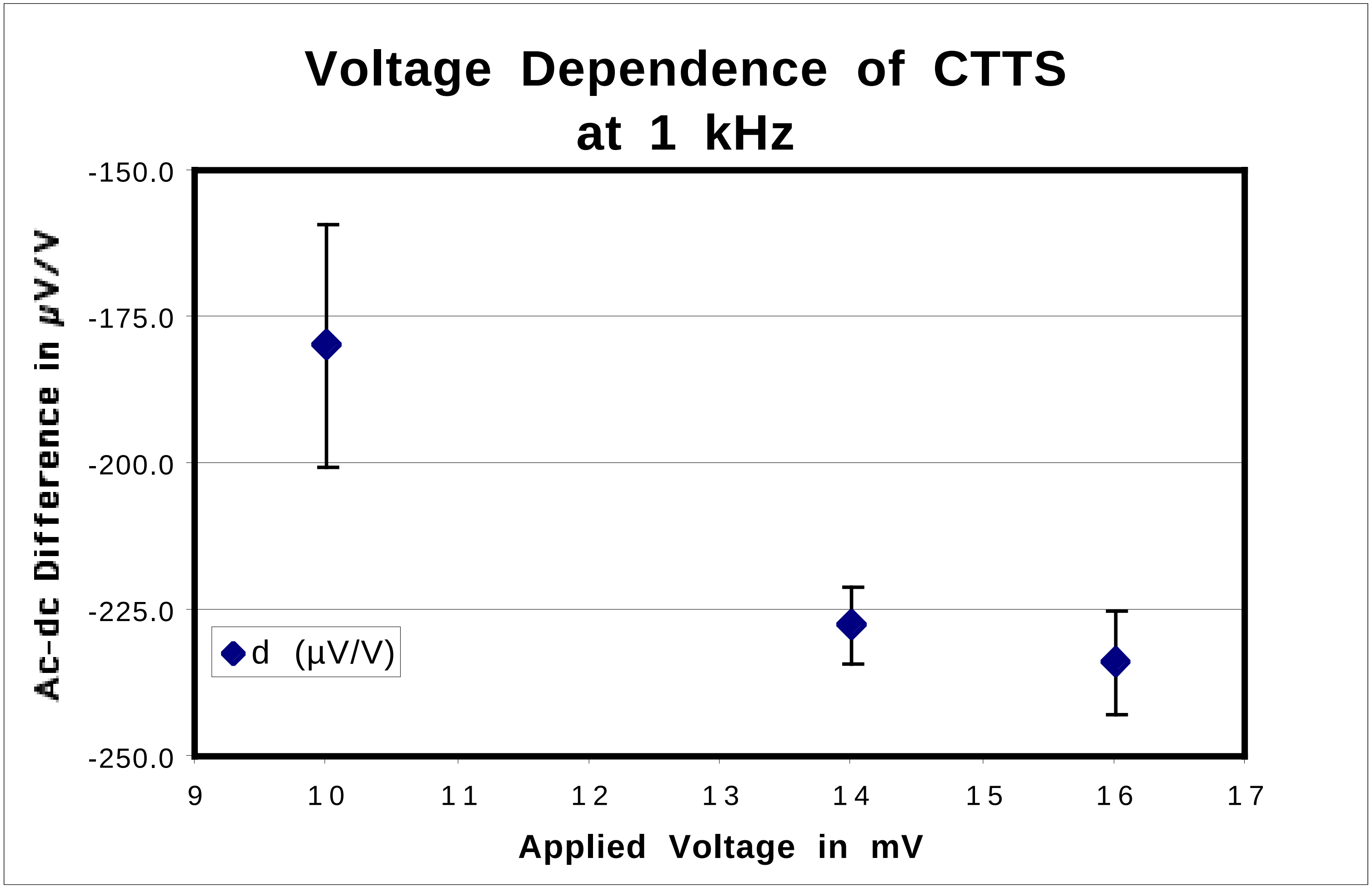
Experimental Data - TVC



Experimental Data - FRDC



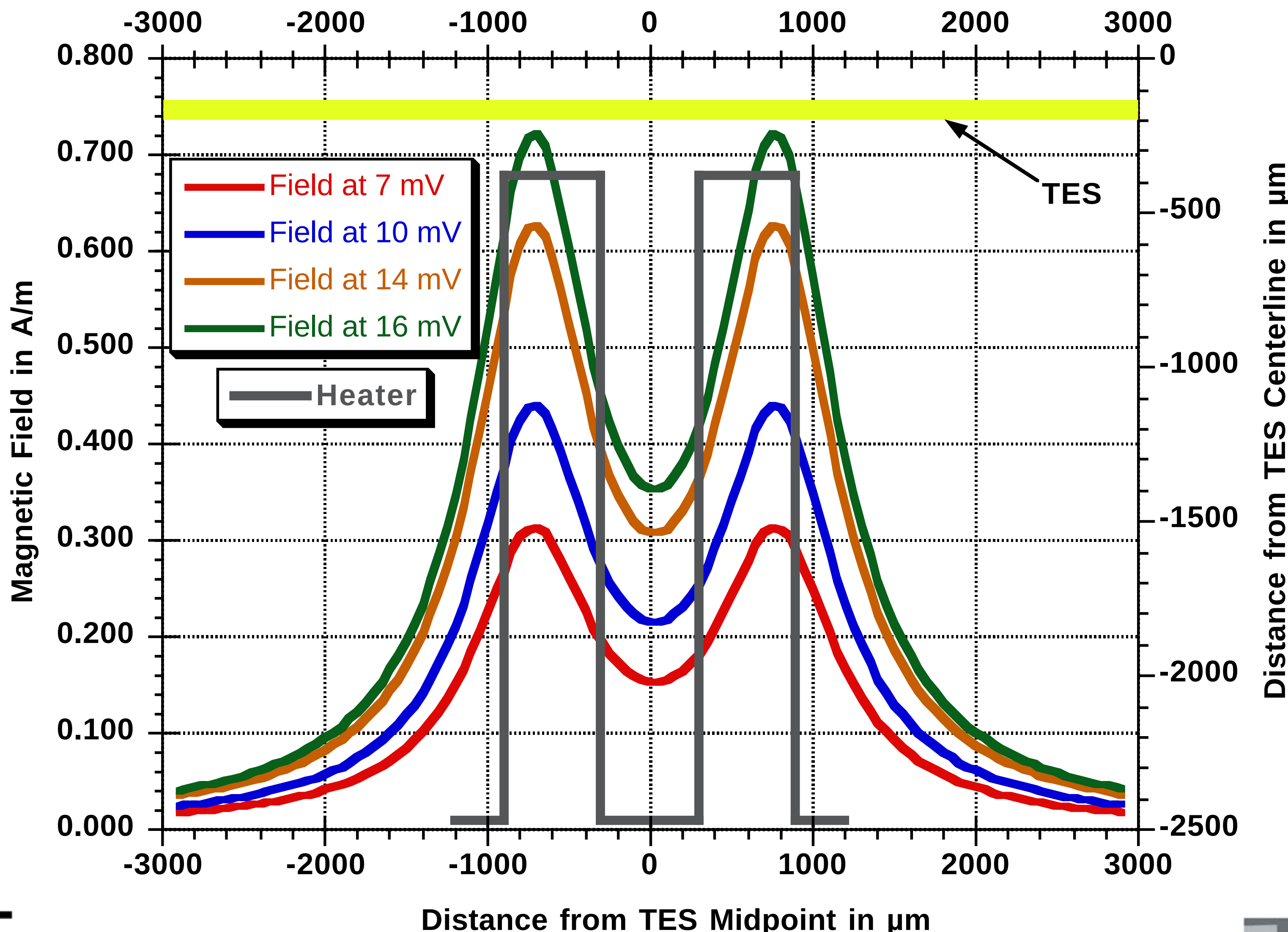
Experimental Data - Level



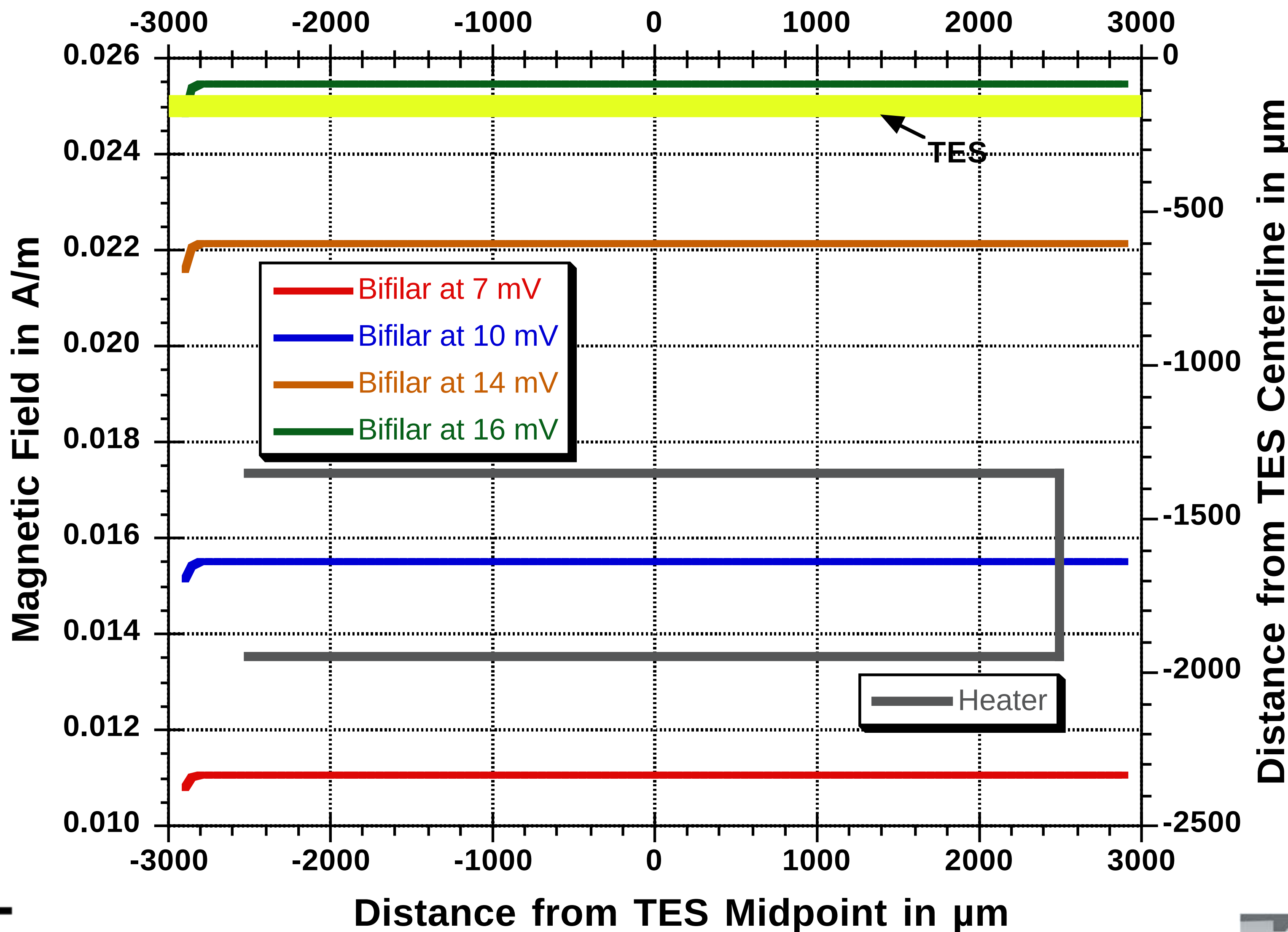
Conclusions From Data

- High-frequency errors due to transmission line structures
- FRDC measurements indicate that audio-frequency errors are not due to thermoelectric effects in the sensor
- Ac-dc differences strongly dependent on input power level
- ***Probable mechanism: Tc suppression caused by magnetic fields on the chip***

Magnetic Fields - Present Chip



Magnetic Fields - New Chip



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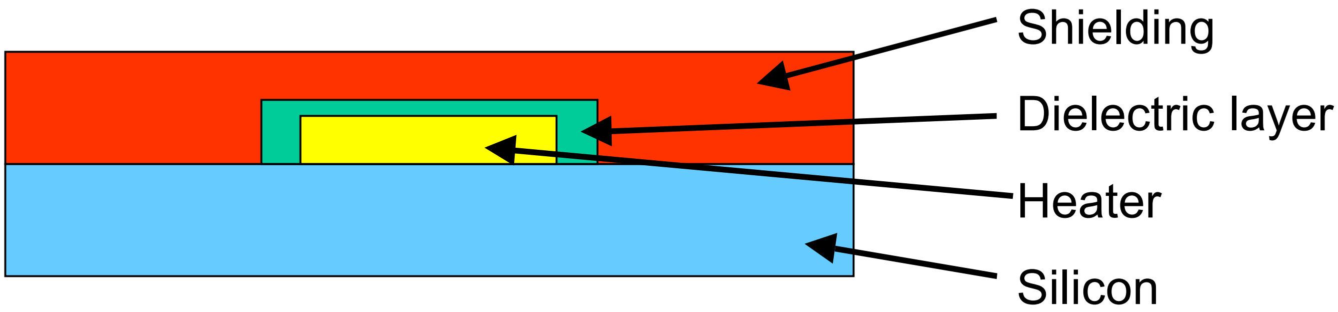
Future Plans - I

- Reduce magnetic field coupling from the heater to the TES
  - Change heater design to bifilar structure
  - Use on-chip shielding or coaxial structure



Cross-section of chip

Future Plans -II

- Improve high-frequency characteristics by improving input transmission structure.
  - Integrate experimental platform and transmission line
  - Place transmission line on TES chip
- Improve room-temperature electronics
- Improve resistance measurements
- Improve PID control

Conclusions

- Cryogenic Thermal Transfer Standard constructed and tested
- High-T_c transmission line installed and tested
- Measurements indicate that audio-frequency errors result from magnetic coupling
  - Redesign heater structure and shield TES
- Viable approach to new primary standard of ac-dc difference